



## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

|   |           |  |
|---|-----------|--|
| <b>(51) International Patent Classification <sup>5</sup> :</b><br><b>B21H 5/02, B22F 5/08</b><br><b>C21D 7/04</b>   | <b>A1</b> | <b>(11) International Publication Number:</b> <b>WO 92/05897</b><br><b>(43) International Publication Date:</b> 16 April 1992 (16.04.92)   |
| <b>(21) International Application Number:</b> PCT/GB91/01742<br><b>(22) International Filing Date:</b> 8 October 1991 (08.10.91)<br><br><b>(30) Priority data:</b><br>9021833.0                      8 October 1990 (08.10.90)                      GB<br><br><b>(71) Applicant (for all designated States except US):</b> FORMFLO LIMITED [GB/GB]; Lansdown Industrial Estate, Gloucester Road, Cheltenham GL51 8PW (GB).<br><br><b>(72) Inventor; and</b><br><b>(75) Inventor/Applicant (for US only) :</b> COLE, Christopher, John [GB/GB]; 'Shieling', Fleet Lane, Twynning, Tewkesbury, Gloucester GL20 6DG (GB).<br><br><b>(74) Agent:</b> LLOYD WISE, TREGEAR & CO.; Norman House, 105-109 Strand, London WC2R 0AE (GB). |           | <b>(81) Designated States:</b> AT, AT (European patent), AU, BB, BE (European patent), BF (OAPI patent), BG, BJ (OAPI patent), BR, CA, CF (OAPI patent), CG (OAPI patent), CH, CH (European patent), CI (OAPI patent), CM (OAPI patent), DE, DE (European patent), DK, DK (European patent), ES, ES (European patent), FI, FR (European patent), GA (OAPI patent), GB, GB (European patent), GN (OAPI patent), GR (European patent), HU, IT (European patent), JP, KP, KR, LK, LU, LU (European patent), MC, MG, ML (OAPI patent), MR (OAPI patent), MW, NL, NL (European patent), NO, PL, RO, SD, SE, SE (European patent), SN (OAPI patent), SU <sup>+</sup> , TD (OAPI patent), TG (OAPI patent), US.<br><br>Published<br>With international search report. |
| <b>(54) Title:</b> GEAR WHEELS ROLLED FROM POWDER METAL BLANKS<br><br><div data-bbox="300 1291 1453 1627" data-label="Image"> </div><br><b>(57) Abstract</b><br><p>A gear wheel is formed from a pressed and sintered powder metal blank (2) by surface hardening the tooth, root and flank regions to establish densification in the range of 90 to 100 per cent to a depth of at least 380 microns.</p>   |           |  |

# + DESIGNATIONS OF "SU"

Any designation of "SU" has effect in the Russian Federation. It is not yet known whether any such designation has effect in other States of the former Soviet Union.

## *FOR THE PURPOSES OF INFORMATION ONLY*

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

|    |                          |    |                                       |                 |                          |
|----|--------------------------|----|---------------------------------------|-----------------|--------------------------|
| AT | Austria                  | ES | Spain                                 | MG              | Madagascar               |
| AU | Australia                | FI | Finland                               | ML              | Mali                     |
| BB | Barbados                 | FR | France                                | MN              | Mongolia                 |
| BE | Belgium                  | GA | Gabon                                 | MR              | Mauritania               |
| BF | Burkina Faso             | GB | United Kingdom                        | MW              | Malawi                   |
| BG | Bulgaria                 | GN | Guinea                                | NL              | Netherlands              |
| BJ | Benin                    | GR | Greece                                | NO              | Norway                   |
| BR | Brazil                   | HU | Hungary                               | PL              | Poland                   |
| CA | Canada                   | IT | Italy                                 | RO              | Romania                  |
| CF | Central African Republic | JP | Japan                                 | SD              | Sudan                    |
| CG | Congo                    | KP | Democratic People's Republic of Korea | SE              | Sweden                   |
| CH | Switzerland              | KR | Republic of Korea                     | SN              | Senegal                  |
| CI | Côte d'Ivoire            | LI | Liechtenstein                         | SU <sup>+</sup> | Soviet Union             |
| CM | Cameroon                 | LK | Sri Lanka                             | TD              | Chad                     |
| CS | Czechoslovakia           | LJ | Luxembourg                            | TG              | Togo                     |
| DE | Germany                  | MC | Monaco                                | US              | United States of America |
| DK | Denmark                  |    |                                       |                 |                          |

GEAR WHEELS ROLLED FROM POWDER METAL BLANKS

This invention relates to a method of producing gear wheels from powder metal blanks. The invention is particularly concerned with achieving a degree of surface hardness which enables such gear wheels to be sufficiently wear resistant for use in heavy duty applications. Particular applications contemplated are for power transmission such as in vehicle gear boxes where high loadings and speeds must be accommodated.

Gears formed from sintered powder metal blanks are well known. British Patent Specification No. 1125952 discloses a method of producing gear wheels from powder metal blanks in which, after pressing the powder and sintering, the gear wheel is rolled to properly size the teeth and teeth root diameters. The manufacture of both spur and helical gears is contemplated.

A primary problem with gear wheels formed from powder metal blanks is that when compared with gears machined from bar stock, castings or forgings, powder metal gear wheels have reduced bending fatigue strength in the tooth root region, and low wear resistance on the tooth flanks due to the residual porosity in the microstructure. For these reasons, while powder metal gear wheels can be used in low stress applications such as oil pumps, they were not suitable for power transmission. As power transmission applications use predominantly helical gears, there has been very little use of helical gears made from powder metal blanks in highly loaded transmission applications.

We have found that substantial improvements in the bending strength and wear resistance of gears in powder metal gear wheels can be achieved if sufficient densification of the gear surface, and to sufficient depths, is established. According to the invention, a gear wheel formed from a pressed and sintered powder metal blank is surface hardened by rolling in the tooth, root and flank regions to establish densification in the

range of 90 to 100 percent to a depth of at least 380 microns. The core density; ie below the densified regions, is usually substantially uniform, typically at around 90 percent. Normally the depth of densification is in the range 380 to 500 microns. We have found that little additional benefit is achieved if the depth of densification exceeds 1000 microns. The density at the surface is substantially 100%, and remains at a density no less than 90% at least to the minimum depth specified.

The rate at which the density reduces with respect to depth is normally at least linear; ie, the minimum density in the hardened regions is directly inversely proportional to the depth. Usually, the density at least in regions closer to the surface will be significantly greater than this minimum value. Typically, the rate of density reduction will be very low at the surface and increase uniformly towards the maximum depth of the hardened regions. Thus the density might vary in relation to the square or a higher power of the depth.

The metal powders used in gears according to the invention will be selected according to the eventual application, and can include low alloy steel grades similar to those used in the manufacture of high performance gears from other forms of metal. The powders can be either admixed elemental iron plus alloying additions, or fully pre-alloyed powders. Typical fully pre-alloyed powders would be of a composition such as AISI 4600 and its derivatives. Admixed powders have the advantage of being more compressible, enabling higher densities to be reached at the compaction stage. In addition, the use of admixed powders enables compositions to be tailored to specific applications. For example, elemental powders may be blended together with a lubricant to produce, on sintering, low alloy gears of compositions similar to SAE 4100, SAE 4600, and SAE 8600 grades. Elemental powder additions to the base iron can include Carbon, Chromium, Molybdenum, Manganese, Nickel, Copper, and Vanadium. Again, quantities of the additives

will vary with different applications, but will normally be no more than 5 percent by weight in each case.

A preferred admixed powder composition in gears according to the invention has the following composition

5 by weight:

|            |      |
|------------|------|
| Carbon     | 0.2% |
| Chromium   | 0.5% |
| Manganese  | 0.5% |
| Molybdenum | 0.5% |

10 the balance being iron and unavoidable impurities.

It will be recognised that the use of Chromium, Molybdenum and Manganese in the formation of a sintered powder metal blank requires a sintering process which can minimise their oxidation. A preferred process used in  
15 this invention is to sinter at high temperature up to 1350°C in a very dry Hydrogen/Nitrogen atmosphere, for example at a dew point of -40°C. This has the additional benefit of further improving mechanical properties and reducing oxygen levels to approximately 200ppm.

20 The alloying addition powders used in gears according to the invention will preferably have a particle size in the range 2 to 10 microns. Generally, particle sizes in this range can be achieved by fine grinding of ferroalloys in an appropriate inert  
25 atmosphere. Prevention of oxidation of readily oxidisable alloying powders at the grinding stage can be critical to the achievement of the degrees of densification referred to above.

Densification of the operative surface layer of a  
30 powder metal gear as specified above may be accomplished in a number of rolling techniques. These may employ either a single die or twin die rolling machine, and may include separate and/or simultaneous root and flank rolling. In each case, the or each rolling die is  
35 normally in the form of a mating gear made from hardened tool steel. In use, the die is engaged with the sintered gear blank, and as the two are rotated their axes are brought together to compact and roll the selected areas

of the blank surface. When a predetermined axle spacing has been reached, rotation only will usually continue for a given number of gear revolutions, or dwell time, and then the two parts will be withdrawn from one another.

5 The predetermined axle spacing will of course depend on the size of the gear and die as well as the material of the blank and the desired densification. Typically, the respective rolled surface will be compacted by around 120 microns.

10 Some rolling techniques embodying the invention will now be described by way of example, and with reference to the accompanying schematic drawings wherein:

- Figure 1 is a partially broken side elevation of a single die rolling machine;
- 15 - Figure 2 is a partially broken side elevation of a twin die rolling machine;
- and Figures 3 to 5 are detailed views showing different die geometries used for different rolling functions.

20 In the rolling machine of Figure 1 the powder metal blank 2 is showed mounted on a fixed axle 4, itself supported on a frame 6. A die 8 is rotatably mounted on an axle 10 supported on a carriage 12 which is slidably mounted on the frame 6. The carriage 12 is movable on  
25 the frame 6 towards and away from the axle 4 to bring the die 8 into and out of engagement with the alloy metal blank 2. Such movement is imparted to the carriage 12 by an mechanism, details of which are omitted. The carriage 12 is constrained to move relative  
30 to the frame 6 along a linear path, and the degree of permitted advance is limited by a stop 14. Also mounted on the carriage 12 is a drive mechanism (not shown) for rotating the die 8 above the axis 10. The drive mechanism may comprise a simple motor coupled to an  
35 appropriate wheel for engaging the teeth of the die. For reasons which will be explained below, the drive mechanism should be operable to rotate the die 8 in both senses.

In the conduct of the process according to the invention according to the machine of Figure 1, the powder metal blank is mounted on the axle 4, and the appropriate die mounted on the axle 10, and suitably  
5 coupled to the drive mechanism. The carriage 12 is advanced to engage the teeth of the die to the teeth of the blank, when the drive mechanism is actuated to rotate both the die and the blank in mesh with one another. As the die and blank rotate, the carriage continues to  
10 advance and the teeth of the die 8 roll and densify the respective surfaces of the blank 2 with which they are in contact. The carriage advances up to a full depth position defined by the stop 14. Rolling continues at this depth for a predetermined period of time or number  
15 of revolutions of the blank, and the carriage is then withdrawn still with the die and blank rotating.

During the rolling processes above described, the rotation of the die and blank may be reversed on a number of occasions. Intermittent reversal throughout the  
20 process may be appropriate, and the frequency of such reversals can be set by numbers of rotations of the die or the blank.

The machine of Figure 2 operates in a substantially similar manner to that of Figure 1, and corresponding  
25 parts are similarly identified. Essentially, the machine of Figure 2 has a pair of dies 8 operating simultaneously of the same blank 2. Advance and retraction of the carriages 12 is synchronised by means of a simple lever system 16. In other respects the same  
30 criteria may be adopted as are described above with reference to Figure 1. Additionally of course, the rotation of the dies 8 must be synchronised. Although it is possible to use only a single drive mechanism coupled to one of the dies, it is normally preferred to  
35 use two, synchronised electronically.

As noted above, in rolling a powder metal gear blank in accordance with the invention, a number of different types of rolling can be achieved depending upon the

profile of the blank and die or dies, and the type of rolling required. Primarily, it is the roots and the flanks of the gear teeth that must be rolled to obtain the surface densification required to achieve the performance improvements discussed above. In Figures 3 to 5, the same blank profile is shown. A die having different teeth profiles are used to effect rolling on different portions of the surfaces of the blank teeth.

In Figure 3, flank rolling only is illustrated. As the die and blank rotate together, the flanks of the die teeth 18 roll and wipe against the flanks of the blank teeth 20 as the carriage or carriages 12 advance towards the blank axis. As a consequence, the material at the surface of the flanks of the blank teeth 20 is compacted to form the densified layer 22. It will be noted that at no time does the tip of a die tooth 18 engage the root of the blank teeth 20. This is ensured by the stop 14. The profiles of the die teeth 18 and the blank teeth 20 are selected to ensure that no such contact is made while nevertheless achieving the desired compaction in the regions 22.

In Figure 4, the profile of the die teeth is altered such that rolling is effected simultaneously at the root and on the flank of the blank teeth. This results in a continuous compacted region 24 which extends between the tips of adjacent blank teeth as shown.

In Figure 5, another alternative profile for the die teeth is chosen to achieve root rolling only. In this case, the compacted region 26 is much more restricted than in either of the variants of Figures 3 and 4.

It will be appreciated from the above description of Figures 3 to 5 that different areas of compaction can be established on and between the teeth of a powder metal blank using fairly straightforward rolling techniques and selecting appropriate profiles for the die teeth. The depth of rolling can also be adjusted by means of the stop mechanism 14, and this too will be a controlling factor in the process. Further, in accordance with the

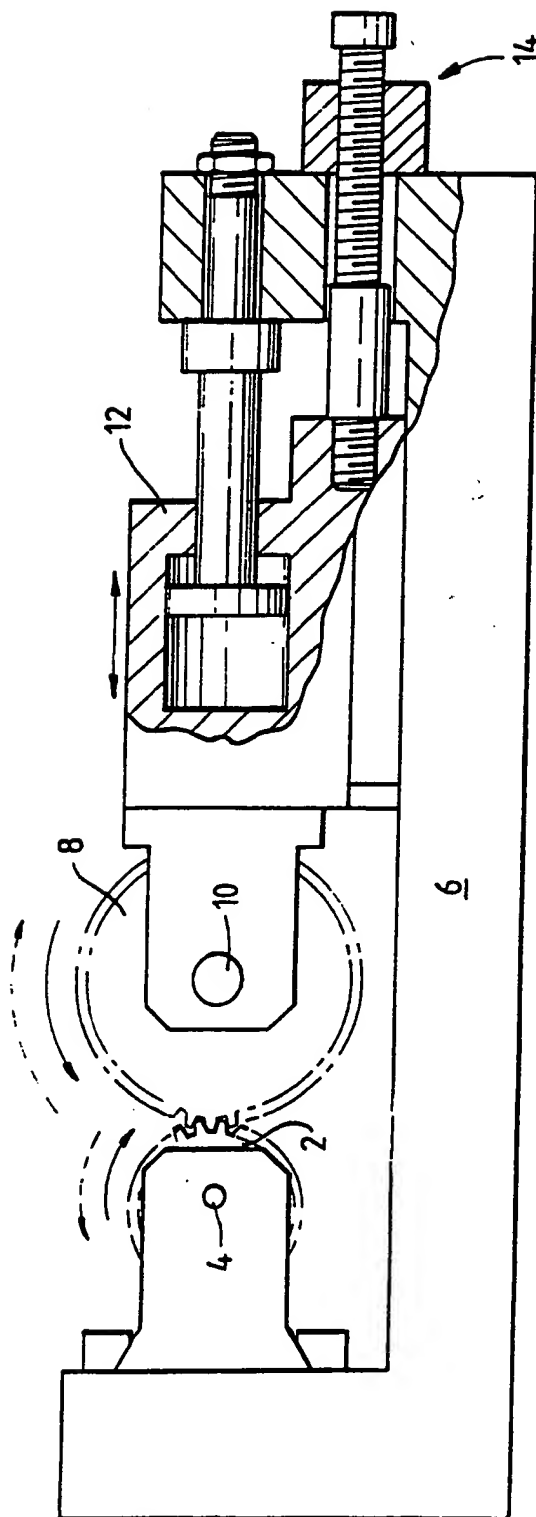
invention different die teeth profiles can be used either separately or simultaneously on the same blank to achieve the required densification and in this context it should be noted that different degrees of densification of the  
5 blank may be desired in different regions depending upon the eventual use of the manufactured gear.  
Densification at the root is desirable to enhance the bending strength; ie, prevent the teeth from breaking away from the body of the gear. Densification along the  
10 flank is desirable for wear resistance.

The above discussion refers essentially to the formation of spur gears from powder metal blanks. However, it will readily be recognised that exactly the same techniques and variations can be adopted in the  
15 manufacture of helical gears. The present invention is equally applicable to both.

CLAIMS

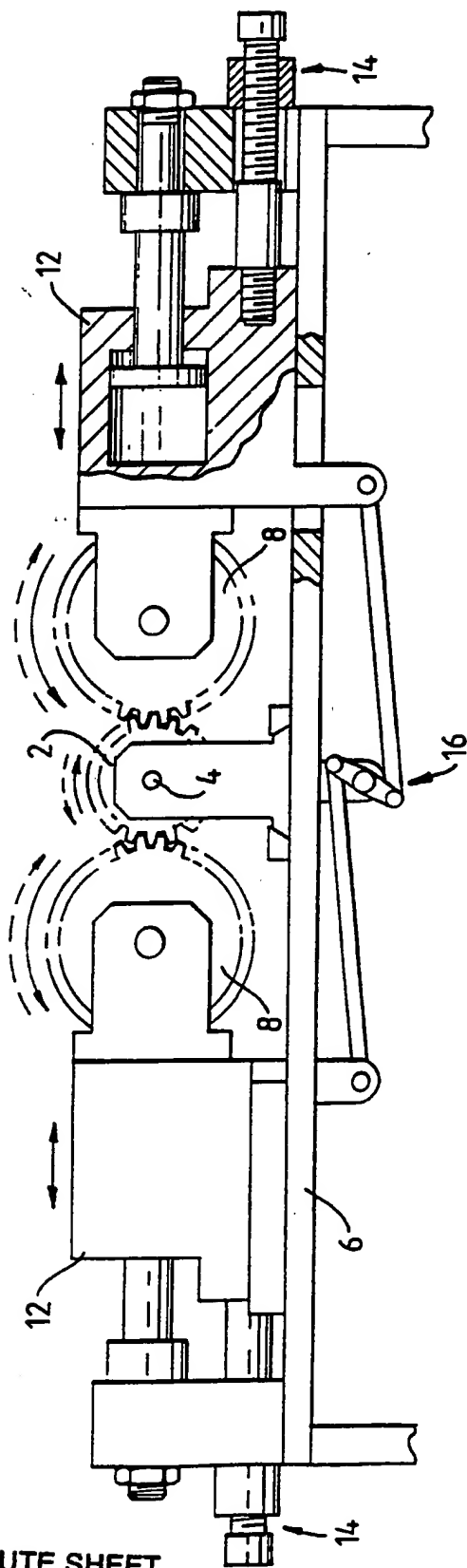
1. A gear wheel formed from a pressed and sintered powder metal blank CHARACTERISED IN THAT the wheel is  
5 surface hardened in the tooth, root and flank regions to establish densification in the range of 90 to 100 per cent to a depth of at least 380 microns.
2. A gear wheel according to Claim 1 wherein the density at the hardened surfaces of the wheel is  
10 substantially 100 per cent.
3. A gear wheel according to Claim 1 or Claim 2 wherein the rate at which the metal density reduces with respect to depth is at least linear.
4. A gear wheel according to Claim 3 wherein the  
15 rate of density reduction is relatively low at the surface, and increases uniformly towards the maximum depth of the hardened regions.
5. A gear wheel according to any preceding Claim wherein said metal powder comprises an admixture of  
20 elemental iron and at least one alloying addition.
6. A gear wheel according to Claim 5 wherein the alloying additions comprise Carbon, Chromium, Manganese, and Molybdenum.
7. A gear wheel according to any preceding Claim  
25 wherein the particle size of said metal powder is in the range 2 to 10 microns.
8. A method of manufacturing a gear wheel CHARACTERISED BY rolling the tooth, root and flank regions of a pressed and sintered powder metal blank to  
30 establish densification in the range of 90 to 100 per cent to a depth of at least 380 microns.
9. A method according to Claim 8 wherein said regions are compacted by substantially 120 microns in the rolling process.
- 35 10. A method according to Claim 8 or Claim 9 wherein the blank has been sintered in a dry Hydrogen/Nitrogen atmosphere.

Fig.1.



2/3

Fig.2



SUBSTITUTE SHEET

3/3

Fig.3.

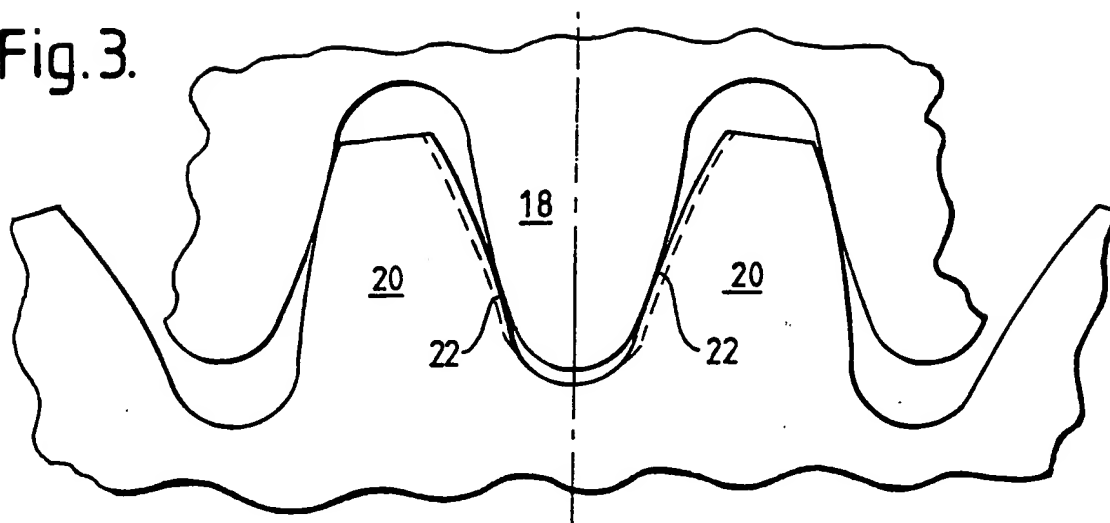


Fig. 4.

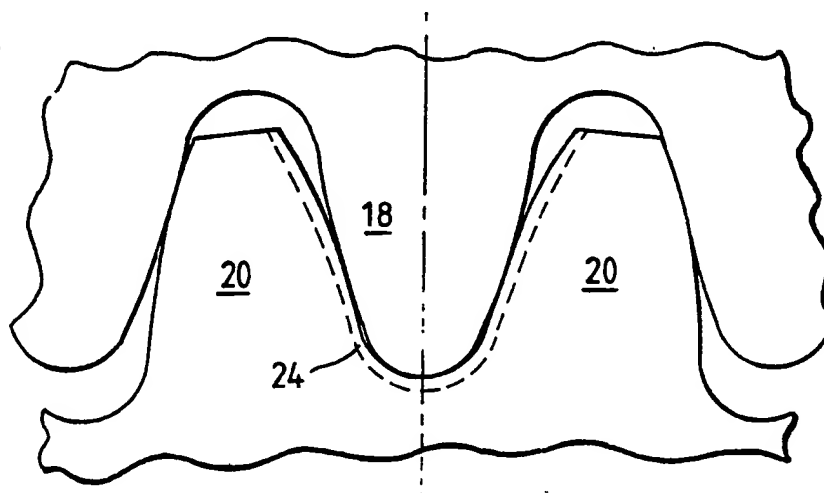
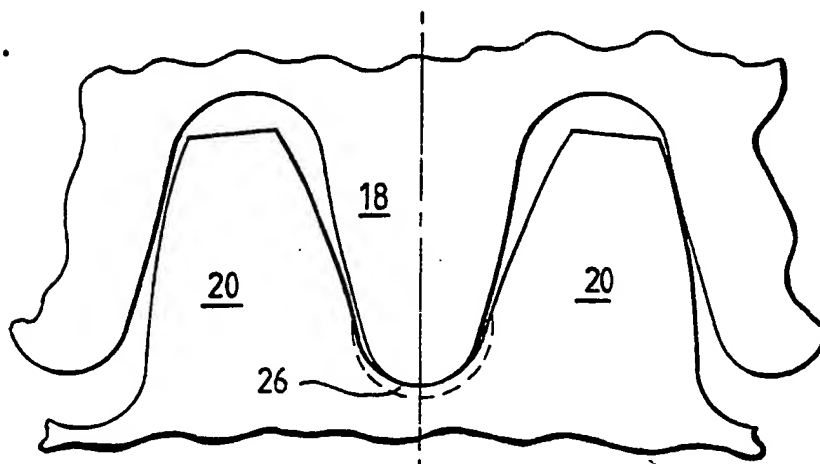


Fig.5.



## INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 91/01742

|  |  |                                     |
|--|--|-------------------------------------|
| <b>I. CLASSIFICATION OF SUBJECT MATTER</b> (If several classification symbols apply, indicate all) <sup>6</sup>  |  |                                     |
| According to International Patent Classification (IPC) or to both National Classification and IPC  |  |                                     |
| Int.Cl. 5 B21H5/02; B22F5/08; C21D7/04   |  |                                     |
| <b>II. FIELDS SEARCHED</b>   |  |                                     |
| Minimum Documentation Searched <sup>7</sup>  |  |                                     |
| Classification System  | Classification Symbols   |                                     |
| Int.Cl. 5  | B21H ; B22F ; B23P ; C21D<br>F16H  |                                     |
| Documentation Searched other than Minimum Documentation<br>to the Extent that such Documents are Included in the Fields Searched <sup>8</sup>  |  |                                     |
| <b>III. DOCUMENTS CONSIDERED TO BE RELEVANT<sup>9</sup></b>  |  |                                     |
| Category <sup>10</sup>   | Citation of Document, <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup>   | Relevant to Claim No. <sup>13</sup> |
| X  | GB,A,1 532 641 (BRITISH STEEL) 15 November 1978<br>see the whole document<br>----  | 1,2,5,6,<br>8,10                    |
| A  | GB,A,1 125 952 (THE BIRMINGHAM SMALL ARMS CO.) 5<br>September 1968<br>cited in the application<br>see the whole document<br>----                       | 1,8                                 |
| A  | US,A,4 708 912 (HUPPMANN) 24 November 1987<br>see the whole document<br>----   | 1,8                                 |
| A  | JP,A,2 138 554 (NISSAN MOTOR CO.) 28 May 1990<br>see figures<br>& PATENT ABSTRACTS OF JAPAN,<br>vol. 14, no. 378 (M-1011)(4321) 15 August 1990<br>---- | 1,8,10                              |
| A  | US,A,4 059 879 (CHMURA ET AL.) 29 November 1977<br>-----<br>-/-  |                                     |
| <p><sup>10</sup> Special categories of cited documents:</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"A" document member of the same patent family</p> |  |                                     |
| <b>IV. CERTIFICATION</b>   |  |                                     |
| Date of the Actual Completion of the International Search  | Date of Mailing of this International Search Report  |                                     |
| 16 JANUARY 1992  | 31. 01. 92   |                                     |
| International Searching Authority  | Signature of Authorized Officer  |                                     |
| EUR PEAN PATENT OFFICE   | ROSENBAUM H.P.J.<br><i>Rosenbaum</i>   |                                     |

| III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET) |  |                       |
|--|--|-----------------------|
| Category *   | Citation of Document, with indication, where appropriate, of the relevant passages | Relevant to Claim No. |
| A  | US,A,4 394 421 (CHMURA ET AL.) 19 July 1983<br>---                                 |                       |
| A  | GB,A,1 384 388 (FORMFLO) 19 February 1975<br>---                                   |                       |

**ANNEX TO THE INTERNATIONAL SEARCH REPORT  
ON INTERNATIONAL PATENT APPLICATION NO. GB 9101742  
SA 51878**

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on  
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information. 16/01/92

| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s)  | Publication<br>date                          |
|---|---------------------|---|--|
| GB-A-1532641                              | 15-11-78            | None  |  |
| GB-A-1125952                              |                     | DE-A- 1552166<br>NL-A- 6602670                                      | 19-03-70<br>05-09-66                         |
| US-A-4708912                              | 24-11-87            | None  |  |
| JP-A-2138554                              | 28-05-90            | EP-A- 0371340   | 06-06-90                                     |
| US-A-4059879                              | 29-11-77            | CA-A- 1047805<br>DE-A- 2641899<br>GB-A- 1538767<br>JP-A- 52062108   | 06-02-79<br>18-05-77<br>24-01-79<br>23-05-77 |
| US-A-4394421                              | 19-07-83            | CA-A- 1165514<br>DE-A- 3018345<br>GB-A, B 2051639<br>JP-A- 56025907 | 17-04-84<br>05-02-81<br>21-01-81<br>12-03-81 |
| GB-A-1384388                              | 19-02-75            | None  |  |